

REMARKS

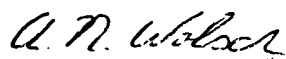
This Supplemental Amendment follows the Response (filed on May 29, 2001) to the first (nonfinal) Office Action mailed by the USPTO on November 27, 2000. Applicant has added new claims 51-63. Claims 1-63 remain pending in the Application. No new matter has been added to the Application. Reconsideration of the pending claims is respectfully requested.

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CONCLUSION

It is respectfully submitted that the pending claims 1-63 are in condition for allowance, and such action is respectfully solicited.

Respectfully submitted,



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Claims

I claim:

1. A power module, comprising:
- an air compressor cell defining a variable-volume air compressor chamber, an air supply port, and an air exit port, said air supply port and air exit port each arranged in fluid communication with the air compressor chamber, said air supply port adapted to communicate with a source of supply air;
 - an electronically-controllable magnetically-latchable air supply valve associated with the air supply port and selectively operable to move between i) a closed position at which the air supply valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port and ii) an opened position at which the air supply valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;
 - an air pump piston positioned in the air compressor chamber and operable to move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;
 - a combustion cell defining a variable-volume combustion chamber separate from the air compressor chamber, an air intake port, and an exhaust port, said air intake port and exhaust port each arranged in fluid communication with the combustion chamber;
 - an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;
 - an intake valve associated with the air intake port of the combustion cell and selectively operable to move between i) a closed position at which the intake valve closes the air intake port and thereby closes fluid communication between the air storage chamber and the combustion chamber via the air intake port and ii) an opened position at which the intake valve opens the air intake port and thereby opens fluid communication between the air storage chamber and the combustion chamber via the air intake port;

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an exhaust valve associated with the exhaust port of the combustion cell and selectively operable to move between i) a closed position at which the exhaust valve closes the exhaust port and thereby closes fluid communication between the combustion chamber and the exhaust port and ii) an opened position at which the exhaust valve opens the exhaust port and thereby opens fluid communication between the combustion chamber and the exhaust port; and

a power piston positioned in the combustion chamber and operable to move therein between i) an expansion position at which the combustion chamber reaches its maximum volume and ii) a contraction position at which the combustion chamber reaches its minimum volume.

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A power module, comprising:

an air compressor cell defining a variable-volume air compressor chamber, an air supply port, and an air exit port, said air supply port and air exit port each arranged in fluid communication with the air compressor chamber, said air supply port adapted to communicate with a source of supply air;

an air supply valve associated with the air supply port and selectively operable to move between i) a closed position at which the air supply valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port and ii) an opened position at which the air supply valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;

an air pump piston positioned in the air compressor chamber and operable to move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;

a combustion cell defining a variable-volume combustion chamber separate from the air compressor chamber, an air intake port, and an exhaust port, said air intake port and exhaust port each arranged in fluid communication with the combustion chamber;

an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;

an intake valve associated with the air intake port of the combustion cell and selectively operable to move between i) a closed position at which the intake valve closes the air intake port and thereby closes fluid communication between the air storage chamber and the combustion chamber via the air intake port and ii) an opened position at which the intake valve opens the air intake port and thereby opens fluid communication between the air storage chamber and the combustion chamber via the air intake port;

an exhaust valve associated with the exhaust port of the combustion cell and selectively operable to move between i) a closed position at which the exhaust valve closes the exhaust port and thereby closes fluid communication between the combustion chamber and the exhaust port and ii) an opened position at which the exhaust valve opens the exhaust port and thereby opens fluid communication between the combustion chamber and the exhaust port; and

a power piston positioned in the combustion chamber and operable to move therein between i) an expansion position at which the combustion chamber reaches its maximum volume and ii) a contraction position at which the combustion chamber reaches its minimum volume, further including an air check valve arranged in fluid communication between said air exit port of the air compressor cell and the air storage chamber, said air check valve operable to allow only one-way fluid flow from the air compressor chamber to the air storage chamber.

³
~~3.~~ A power module, comprising:

an air compressor cell defining a variable-volume air compressor chamber, an air supply port, and an air exit port, said air supply port and air exit port each arranged in fluid communication with the air compressor chamber, said air supply port adapted to communicate with a source of supply air;

an air supply valve associated with the air supply port and selectively operable to move between i) a closed position at which the air supply valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port and ii) an opened

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position at which the air supply valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;

an air pump piston positioned in the air compressor chamber and operable to move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;

a combustion cell defining a variable-volume combustion chamber separate from the air compressor chamber, an air intake port, and an exhaust port, said air intake port and exhaust port each arranged in fluid communication with the combustion chamber;

an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;

an intake valve associated with the air intake port of the combustion cell and selectively operable to move between i) a closed position at which the intake valve closes the air intake port and thereby closes fluid communication between the air storage chamber and the combustion chamber via the air intake port and ii) an opened position at which the intake valve opens the air intake port and thereby opens fluid communication between the air storage chamber and the combustion chamber via the air intake port;

an exhaust valve associated with the exhaust port of the combustion cell and selectively operable to move between i) a closed position at which the exhaust valve closes the exhaust port and thereby closes fluid communication between the combustion chamber and the exhaust port and ii) an opened position at which the exhaust valve opens the exhaust port and thereby opens fluid communication between the combustion chamber and the exhaust port; and

a power piston positioned in the combustion chamber and operable to move therein between i) an expansion position at which the combustion chamber reaches its maximum volume and ii) a contraction position at which the combustion chamber reaches its minimum volume, wherein said air supply valve is an electronically-controllable two-way valve including a movable magnetically-latchable poppet having an end portion, a return spring operable to bias the poppet towards one

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P¹
42 position corresponding to the closed position of the air supply valve, and an
43 opening-direction electrical coil located proximate the end portion of the poppet,
44 said opening-direction electrical coil selectively operable to electromagnetically pull
45 the poppet towards another position corresponding to the opened position of the air
46 supply valve.
47

1 ~~4~~⁴ The power module of claim ~~3~~³, further including an electronic control
2 unit operable to selectively and independently control the operation of the air supply
3 valve with digital pulses of electrical current.
4

P²
1 ~~5~~⁷ The power module of claim ~~4~~⁴, further including an air pressure sensor
2 operable to sense the pressure of air in the air storage chamber and provide the
3 electronic control unit with a signal indicative of such pressure, said electronic
4 control unit operable to move the air supply valve to its opened position in response
5 to said pressure being below a threshold air pressure, said electronic control unit
6 operable to move the air supply valve to its closed position in response to said
7 pressure being at least the threshold air pressure.
8

P³
1 ~~6~~⁸ The power module of claim ~~5~~⁷, wherein the control unit is operable to
2 selectively and independently control the operation of the air supply valve in further
3 response to at least one sensed parameter selected from the group of ambient air
4 temperature, ambient barometric pressure, inlet air temperature, inlet air pressure,
5 actuating fluid temperature, actuating fluid pressure, throttle position, power piston
6 position, engine brake signals, starter inputs, and ignition switch position.
7

P⁴
1 ~~7~~² The power module of claim 1, wherein the air compressor cell and
2 the combustion cell are integrally formed adjacent one another by a common
3 housing.
4

P⁵
1 ~~8~~⁹ A power module, comprising:
2 an air compressor cell defining a variable-volume air compressor chamber,
3 an air supply port, and an air exit port, said air supply port and air exit port each

4 arranged in fluid communication with the air compressor chamber, said air supply
5 port adapted to communicate with a source of supply air;

6 an air supply valve associated with the air supply port and selectively
7 operable to move between i) a closed position at which the air supply valve closes
8 the air supply port and thereby closes fluid communication between the source of
9 supply air and the air compressor chamber via the air supply port and ii) an opened
10 position at which the air supply valve opens the air supply port and thereby opens
11 fluid communication between the source of supply air and the air compressor
12 chamber via the air supply port;

13 an air pump piston positioned in the air compressor chamber and operable to
14 move between i) an expansion position at which the air compressor chamber reaches
15 its maximum volume and ii) a contraction position at which the air compressor
16 chamber reaches its minimum volume;

17 a combustion cell defining a variable-volume combustion chamber separate
18 from the air compressor chamber, an air intake port, and an exhaust port, said air
19 intake port and exhaust port each arranged in fluid communication with the
20 combustion chamber;

21 an air storage chamber arranged in fluid communication between the air exit
22 port of the air compressor cell and the air intake port of the combustion cell;

23 an intake valve associated with the air intake port of the combustion cell and
24 selectively operable to move between i) a closed position at which the intake valve
25 closes the air intake port and thereby closes fluid communication between the air
26 storage chamber and the combustion chamber via the air intake port and ii) an
27 opened position at which the intake valve opens the air intake port and thereby opens
28 fluid communication between the air storage chamber and the combustion chamber
29 via the air intake port;

30 an exhaust valve associated with the exhaust port of the combustion cell and
31 selectively operable to move between i) a closed position at which the exhaust valve
32 closes the exhaust port and thereby closes fluid communication between the
33 combustion chamber and the exhaust port and ii) an opened position at which the
34 exhaust valve opens the exhaust port and thereby opens fluid communication
35 between the combustion chamber and the exhaust port; and

36 a power piston positioned in the combustion chamber and operable to move
37 therein between i) an expansion position at which the combustion chamber reaches
38 its maximum volume and ii) a contraction position at which the combustion chamber
39 reaches its minimum volume, wherein the air pump piston and the power piston are
40 movable by a common drive device.

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1 ¹⁰~~9~~ The power module of claim ⁹~~8~~, wherein said common drive device
2 includes a rotatable crankshaft.

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1 ³~~10~~ The power module of claim 1, further including a direct-injection fuel
2 injector extending into the combustion chamber and selectively operable to inject
3 fuel therein.

4

1 11. A power module, comprising:
2 a turbocharger including an exhaust gas inlet and a compressed air outlet;
3 an air compressor cell defining a variable-volume air compressor chamber, a
4 free air supply port adapted to communicate with atmosphere, at least one
5 turbocharged air supply port arranged in fluid communication with the compressed
6 air outlet of the turbocharger, and an air exit port, said free air supply port,
7 turbocharged air supply port, and air exit port each arranged in separate fluid
8 communication with the air compressor chamber;

9 an electronically-controllable magnetically-latchable free air supply valve
10 associated with the free air supply port and selectively operable to move between i) a
11 closed position at which the air supply valve closes the air supply port and thereby
12 closes fluid communication between atmosphere and the air compressor chamber via
13 the free air supply port and ii) an opened position at which the free air supply valve
14 opens the free air supply port and thereby opens fluid communication between
15 atmosphere and the air compressor chamber via the free air supply port;

16 an electronically-controllable magnetically-latchable turbocharged air supply
17 valve associated with each turbocharged air supply port and selectively operable to
18 move between i) a closed position at which the turbocharged air supply valve closes
19 its respective turbocharged air supply port and thereby closes fluid communication

20 between the compressed air outlet of the turbocharger and the air compressor
21 chamber via the respective turbocharged air supply port and ii) an opened position at
22 which the turbocharged air supply valve opens its respective turbocharged air supply
23 port and thereby opens fluid communication between the compressed air outlet of
24 the turbocharger and the air compressor chamber via the respective turbocharged air
25 supply port;

26 an air pump piston positioned in the air compressor chamber and operable to
27 move between i) an expansion position at which the air compressor chamber reaches
28 its maximum volume and ii) a contraction position at which the air compressor
29 chamber reaches its minimum volume;

30 a combustion cell defining a variable-volume combustion chamber separate
31 from the air compressor chamber, an air intake port, a free exhaust port adapted to
32 communicate with atmosphere, and at least one drive exhaust port arranged in fluid
33 communication with the exhaust gas inlet of the turbocharger, said air intake port,
34 free exhaust port, and drive exhaust port each arranged in separate fluid
35 communication with the combustion chamber;

36 an air storage chamber arranged in fluid communication between the air exit
37 port of the air compressor cell and the air intake port of the combustion cell;

38 an intake valve associated with the air intake port of the combustion cell and
39 selectively operable to move between i) a closed position at which the intake valve
40 closes the air intake port and thereby closes fluid communication between the air
41 storage chamber and the combustion chamber via the air intake port and ii) an
42 opened position at which the intake valve opens the air intake port and thereby opens
43 fluid communication between the air storage chamber and the combustion chamber
44 via the air intake port;

45 a free exhaust valve associated with the free exhaust port of the combustion
46 cell and selectively operable to move between i) a closed position at which the free
47 exhaust valve closes the free exhaust port and thereby closes fluid communication
48 between the combustion chamber and atmosphere via the free exhaust port and ii) an
49 opened position at which the free exhaust valve opens the free exhaust port and
50 thereby opens fluid communication between the combustion chamber and
51 atmosphere via the free exhaust port;

52 a drive exhaust valve associated with each drive exhaust port of the
53 combustion cell and selectively operable to move between i) a closed position at
54 which the drive exhaust valve closes its respective drive exhaust port and thereby
55 closes fluid communication between the combustion chamber and the exhaust gas
56 inlet of the turbocharger via the respective drive exhaust port and ii) an opened
57 position at which the drive exhaust valve opens its respective drive exhaust port and
58 thereby opens fluid communication between the combustion chamber and the
59 exhaust gas inlet of the turbocharger via the respective drive exhaust port; and
60 a power piston positioned in the combustion chamber and operable to move
61 therein between i) an expansion position at which the combustion chamber reaches
62 its maximum volume and ii) a contraction position at which the combustion chamber
63 reaches its minimum volume.

64
B7 1 12. A power module, comprising:

2 an actuating fluid compressor cell defining a variable-volume actuating fluid
3 compressor chamber and an actuating fluid port arranged in fluid communication
4 with the actuating fluid compressor chamber, said actuating fluid port adapted to
5 communicate with a source of actuating fluid;

6 an actuating fluid drain passage;

7 an actuating fluid supply valve arranged in fluid communication between the
8 source of actuating fluid and the actuating fluid port and selectively operable to
9 move between i) a closed position at which the supply valve closes fluid
10 communication between the source of actuating fluid and the actuating fluid
11 compressor chamber via the actuating fluid port and ii) an opened position at which
12 the supply valve opens fluid communication between the source of actuating fluid
13 and the actuating fluid compressor chamber via the actuating fluid port;

14 an actuating fluid pump piston positioned in the actuating fluid compressor
15 chamber and operable to move therein between i) an expansion position at which
16 the actuating fluid compressor chamber reaches its maximum volume and ii) a
17 contraction position at which the actuating fluid compressor chamber reaches its
18 minimum volume;

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19 a combustion cell defining a variable-volume combustion chamber, separate
20 from the actuating fluid compressor chamber, an air intake port, an exhaust port, and
21 an actuating fluid common rail, said air intake port and exhaust port each arranged in
22 fluid communication with the combustion chamber;

23 an actuating fluid storage chamber arranged in fluid communication between
24 the actuating fluid port of the actuating fluid compressor cell and the actuating fluid
25 common rail;

26 a hydraulically-actuatable intake valve associated with the air intake port of
27 the combustion cell and having an actuating fluid chamber and a piston portion
28 positioned in the actuating fluid chamber, said intake valve selectively operable to
29 move between i) a closed position at which the intake valve closes the air intake port
30 and thereby closes fluid communication to the combustion chamber via the air intake
31 port and ii) an opened position at which the intake valve opens the air intake port
32 and thereby opens fluid communication to the combustion chamber via the air intake
33 port;

34 an electronically-controllable magnetically-latchable first control valve
35 arranged in fluid communication between the actuating fluid common rail and the
36 actuating fluid chamber of the intake valve, said first control valve selectively
37 operable to move between i) a closed position at which the first control valve closes
38 fluid communication between the actuating fluid common rail and the actuating fluid
39 chamber of the intake valve and opens fluid communication between the actuating
40 fluid drain passage and the actuating fluid chamber of the intake valve thereby
41 allowing the intake valve to be moved towards its closed position and ii) an opened
42 position at which the first control valve opens fluid communication between the
43 actuating fluid common rail and the actuating fluid chamber of the intake valve and
44 closes fluid communication between the actuating fluid drain passage and the
45 actuating fluid chamber of the intake valve thereby allowing the intake valve to be
46 hydraulically moved towards its opened position ;

47 a hydraulically-actuatable exhaust valve associated with the exhaust port of
48 the combustion cell and having an actuating fluid chamber and a piston portion
49 positioned in the actuating fluid chamber, said exhaust valve selectively operable to
50 move between i) a closed position at which the exhaust valve closes the exhaust port

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51 and thereby closes fluid communication between the combustion chamber and the
52 exhaust port and ii) an opened position at which the exhaust valve opens the exhaust
53 port and thereby opens fluid communication between the combustion chamber and
54 the exhaust port;

55 an electronically-controllable magnetically-latchable second control valve
56 arranged in fluid communication between the actuating fluid common rail and the
57 actuating fluid chamber of the exhaust valve, said second control valve selectively
58 operable to move between i) a closed position at which the second control valve
59 closes fluid communication between the actuating fluid common rail and the
60 actuating fluid chamber of the exhaust valve and opens fluid communication
61 between the actuating fluid drain passage and the actuating fluid chamber of the
62 exhaust valve thereby allowing the exhaust valve to be moved towards its closed
63 position and ii) an opened position at which the second control valve opens fluid
64 communication between the actuating fluid common rail and the actuating fluid
65 chamber of the exhaust valve and closes fluid communication between the actuating
66 fluid drain passage and the actuating fluid chamber of the exhaust valve thereby
67 allowing the exhaust valve to be hydraulically moved towards its opened position;
68 and

69 a power piston positioned in the combustion chamber and operable to move
70 therein between i) an expansion position at which the combustion chamber reaches
71 its maximum volume and ii) a contraction position at which the combustion chamber
72 reaches its minimum volume.
73

1 13. The power module of claim 12, further including a check valve
2 arranged in fluid communication between the actuating fluid port of the actuating
3 fluid compressor cell and the actuating fluid storage chamber, said check valve
4 operable to allow only one-way fluid flow from the actuating fluid compressor
5 chamber to the actuating fluid storage chamber.
6

1 14. The power module of claim 12, wherein said actuating fluid supply
2 valve includes a digitally-controlled two-way valve including a movable
3 magnetically-latchable spool having one end portion and an opposite end portion, a

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4 closing-direction electrical coil located proximate the one end portion of the spool,
5 and an opening-direction electrical coil located proximate the opposite end portion
6 of the spool, said closing-direction electrical coil selectively operable to
7 electromagnetically pull the spool towards one state corresponding to the closed
8 position of the actuating fluid supply valve, said opening-direction electrical coil
9 selectively operable to electromagnetically pull the spool towards another state
10 corresponding to the opened position of the actuating fluid supply valve.
11

1 15. The power module of claim 12, wherein said first and second control
2 valves each include a digitally-controlled three-way valve including a movable
3 magnetically-latchable spool having one end portion and an opposite end portion, a
4 closing-direction electrical coil located proximate the one end portion of the spool,
5 and an opening-direction electrical coil located proximate the opposite end portion
6 of the spool, said closing-direction electrical coil selectively operable to
7 electromagnetically pull the spool towards one state corresponding to the closed
8 position of the first control valve, said opening-direction electrical coil selectively
9 operable to electromagnetically pull the spool towards another state corresponding to
10 the opened position of the first control valve.
11

1 16. The power module of claim 12, further including an electronic control
2 unit operable to control the selectable operation of each said electronically-
3 controllable valves.
4

1 17. The power module of claim 16, further including an actuating fluid
2 pressure sensor operable to i) sense the pressure of actuating fluid in the actuating
3 fluid storage chamber and ii) provide the electronic control unit with an actuating
4 fluid pressure signal indicative of said pressure, said electronic control unit operable
5 to independently control the operation of the actuating fluid supply valve in response
6 to said actuating fluid pressure signal.
7

1 18. The power module of claim 16, further including an actuating fluid

2 pressure sensor operable to i) sense the pressure of actuating fluid in the actuating
3 fluid common rail and ii) provide the electronic control unit with an actuating fluid
4 pressure signal indicative of said pressure, said electronic control unit operable to
5 independently control the operation of the first and second control valves in response
6 to said actuating fluid pressure signal.

7
1 19. The power module of claim 16, wherein said electronic control unit
2 further independently controls the operation of the first and second control valves in
3 response to at least one sensed parameter selected from the group of ambient air
4 temperature, ambient barometric pressure, inlet air temperature, inlet air pressure,
5 actuating fluid temperature, actuating fluid pressure, throttle position, power piston
6 position, engine brake signals, starter inputs, and ignition switch position.

7
1 20. The power module of claim 12, further including an
2 electronically-controllable hydraulically-actuatable fuel injector extending into the
3 combustion chamber and selectively operable to inject fuel therein.
4

1 21. The power module of claim 20, wherein said injector includes an
2 actuating fluid chamber, a piston portion positioned in the actuating fluid chamber, a
3 check valve movable between a closed position at which the check valve blocks
4 injection of fuel and an opened position at which the check valve opens injection of
5 fuel, and an electronically-controllable magnetically-latchable third control valve
6 arranged in fluid communication between the actuating fluid common rail and the
7 actuating fluid chamber of the injector, said third control valve selectively operable
8 to move between i) a closed position at which the third control valve closes fluid
9 communication between the actuating fluid common rail and the actuating fluid
10 chamber of the injector and opens fluid communication between the actuating fluid
11 drain passage and the actuating fluid chamber of the injector thereby allowing the
12 check valve of the injector to be moved towards its closed position and ii) an opened
13 position at which the third control valve opens fluid communication between the
14 actuating fluid common rail and the actuating fluid chamber of the injector and
15 closes fluid communication between the actuating fluid drain passage and the

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16 actuating fluid chamber of the injector thereby allowing the check valve to be
17 hydraulically moved towards its opened position.
18

1 22. The power module of claim 21, wherein said injector is a multiple
2 stage injector.
3

1 23. The power module of claim 12, wherein said actuating fluid storage
2 chamber is integrally formed with the actuating fluid compressor cell.
3

1 24. The power module of claim 12, wherein said actuating fluid storage
2 chamber is connected to the actuating fluid compressor cell.
3

1 25. The power module of claim 12, wherein said intake and exhaust
2 valves each further include a return spring operable to bias the respective valve
3 towards its closed position.
4

1 26. The power module of claim 12, wherein the actuating fluid
2 compressor cell and the combustion cell are integrally formed with one another by a
3 common housing.
4

1 27. The power module of claim 12, wherein the actuating fluid
2 compressor cell and the combustion cell are connected together as a compact unit.
3

1 28. The power module of claim 12, wherein the actuating fluid pump
2 piston and the power piston are movable by a common drive device.
3

1 29. A power module, comprising:
2 an air compressor cell defining a variable-volume air compressor chamber,
3 an air supply port, and an air exit port, said air supply port and air exit port each
4 arranged in fluid communication with the air compressor chamber, said air supply
5 port adapted to communicate with a source of supply air;

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an air supply valve associated with the air supply port and selectively operable to move between i) a closed position at which the air supply valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port and ii) an opened position at which the supply valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;

an air pump piston positioned in the air compressor chamber and operable to move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;

a combustion cell defining a variable-volume combustion chamber, separate from the actuating fluid compressor chamber, an air intake port, an exhaust port, and an actuating fluid common rail, said air intake port and exhaust port each arranged in fluid communication with the combustion chamber;

an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;

an air check valve arranged in fluid communication between said air exit port and the air storage chamber, said air check valve operable to allow only one-way fluid flow from the air compressor chamber to the air storage chamber;

an actuating fluid compressor cell defining a variable-volume actuating fluid compressor chamber and an actuating fluid port arranged in fluid communication with the actuating fluid compressor chamber, said actuating fluid port adapted to communicate with a source of actuating fluid;

an actuating fluid drain passage;

an actuating fluid supply valve arranged in fluid communication between the source of actuating fluid and the actuating fluid port and selectively operable to move between i) a closed position at which the supply valve closes fluid communication between the source of actuating fluid and the actuating fluid compressor chamber via the actuating fluid port and ii) an opened position at which the supply valve opens fluid communication between the source of actuating fluid and the actuating fluid compressor chamber via the actuating fluid port;

38 an actuating fluid pump piston positioned in the actuating fluid compressor
39 chamber and operable to move therein between i) an expansion position at which
40 the actuating fluid compressor chamber reaches its maximum volume and ii) a
41 contraction position at which the actuating fluid compressor chamber reaches its
42 minimum volume;

43 an actuating fluid storage chamber arranged in fluid communication between
44 the actuating fluid port of the actuating fluid compressor cell and the actuating fluid
45 common rail;

46 an actuating fluid check valve arranged in fluid communication between the
47 actuating fluid port of the actuating fluid compressor cell and the actuating fluid
48 storage chamber, said actuating fluid check valve operable to allow only one-way
49 fluid flow from the actuating fluid compressor chamber to the actuating fluid storage
50 chamber;

51 a hydraulically-actuatable intake valve associated with the air intake port of
52 the combustion cell and having an actuating fluid chamber and a piston portion
53 positioned in the actuating fluid chamber, said intake valve selectively operable to
54 move between i) a closed position at which the intake valve closes the air intake port
55 and thereby closes fluid communication between the air storage chamber and the
56 combustion chamber via the air intake port and ii) an opened position at which the
57 intake valve opens the air intake port and thereby opens fluid communication
58 between the air storage chamber and the combustion chamber via the air intake port;

59 an electronically-controllable magnetically-latchable first control valve
60 arranged in fluid communication between the actuating fluid common rail and the
61 actuating fluid chamber of the intake valve, said first control valve selectively
62 operable to move between i) a closed position at which the first control valve closes
63 fluid communication between the actuating fluid common rail and the actuating fluid
64 chamber of the intake valve and opens fluid communication between the actuating
65 fluid drain passage and the actuating fluid chamber of the intake valve thereby
66 allowing the intake valve to be moved towards its closed position and ii) an opened
67 position at which the first control valve opens fluid communication between the
68 actuating fluid common rail and the actuating fluid chamber of the intake valve and
69 closes fluid communication between the actuating fluid drain passage and the

70 actuating fluid chamber of the intake valve thereby allowing the intake valve to be
71 hydraulically moved towards its opened position ;

72 a hydraulically-actuatable exhaust valve associated with the exhaust port of
73 the combustion cell and having an actuating fluid chamber and a piston portion
74 positioned in the actuating fluid chamber, said exhaust valve selectively operable to
75 move between i) a closed position at which the exhaust valve closes the exhaust port
76 and thereby closes fluid communication between the combustion chamber and the
77 exhaust port and ii) an opened position at which the exhaust valve opens the exhaust
78 port and thereby opens fluid communication between the combustion chamber and
79 the exhaust port;

80 an electronically-controllable magnetically-latchable second control valve
81 arranged in fluid communication between the actuating fluid common rail and the
82 actuating fluid chamber of the exhaust valve, said second control valve selectively
83 operable to move between i) a closed position at which the second control valve
84 closes fluid communication between the actuating fluid common rail and the
85 actuating fluid chamber of the exhaust valve and opens fluid communication
86 between the actuating fluid drain passage and the actuating fluid chamber of the
87 exhaust valve thereby allowing the exhaust valve to be moved towards its closed
88 position and ii) an opened position at which the second control valve opens fluid
89 communication between the actuating fluid common rail and the actuating fluid
90 chamber of the exhaust valve and closes fluid communication between the actuating
91 fluid drain passage and the actuating fluid chamber of the exhaust valve thereby
92 allowing the exhaust valve to be hydraulically moved towards its opened position;
93 and

94 a power piston positioned in the combustion chamber and operable to move
95 therein between i) an expansion position at which the combustion chamber reaches
96 its maximum volume and ii) a contraction position at which the combustion chamber
97 reaches its minimum volume.
98

1 30. The power module of claim 29, wherein said actuating fluid pump
2 piston is driven by said air pump piston.
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31. A power module, comprising:

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an air compressor cell defining a variable-volume air compressor chamber, an air supply port, and an air exit port, said air supply port and air exit port each arranged in separate fluid communication with the air compressor chamber, said air supply port adapted to communicate with a source of supply air;

an electronically-controllable magnetically-latchable air supply poppet valve associated with the air supply port, said air supply poppet valve including a magnetically-latchable poppet having an end portion and movable between a closed position and an opened position, a return spring operable to bias the poppet of the air supply poppet valve towards its closed position at which the poppet of the air supply poppet valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port, and an opening-direction electrical coil located proximate the end portion of the poppet, said opening-direction electrical coil selectively operable to electromagnetically pull the poppet of the air supply poppet valve towards its opened position at which the poppet of the air supply poppet valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;

an air pump piston positioned in the air compressor chamber and operable to reciprocally move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;

a combustion cell defining a variable-volume internal combustion chamber, separate from the actuating fluid compressor chamber, an air intake port, an exhaust port, and an actuating fluid common rail, said air intake port and exhaust port each arranged in separate fluid communication with the combustion chamber;

an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;

an air check valve arranged in fluid communication between said air exit port and the air storage chamber, said air check valve operable to allow only one-way fluid flow from the air compressor chamber to the air storage chamber;

an actuating fluid compressor cell defining a variable-volume actuating fluid compressor chamber and an actuating fluid port arranged in fluid communication with the actuating fluid compressor chamber, said actuating fluid port adapted to communicate with a source of actuating fluid;

an actuating fluid drain passage;

B' an electronically-controllable magnetically-latchable two-way actuating fluid supply valve arranged in fluid communication between the source of actuating fluid and the actuating fluid port, said actuating fluid supply valve including a magnetically-latchable spool having one end portion and an opposite end portion and movable between a closed position and an opened position, a closing-direction electrical coil located proximate the one end portion of the spool, and an opening-direction electrical coil located proximate the opposite end portion of the spool, said closing-direction electrical coil selectively operable to electromagnetically pull the spool of the actuating fluid supply valve towards its closed position at which the spool of the actuating fluid supply valve closes fluid communication between the source of actuating fluid and the actuating fluid compressor chamber via the actuating fluid port, said opening-direction electrical coil selectively operable to electromagnetically pull the spool of the actuating fluid supply valve towards its opened position at which the spool of the actuating fluid supply valve opens fluid communication between the source of actuating fluid and the actuating fluid compressor chamber via the actuating fluid port;

an actuating fluid pump piston positioned in the actuating fluid compressor chamber and operable to reciprocally move therein between i) an expansion position at which the actuating fluid compressor chamber reaches its maximum volume and ii) a contraction position at which the actuating fluid compressor chamber reaches its minimum volume;

an actuating fluid storage chamber arranged in fluid communication between the actuating fluid port of the actuating fluid compressor cell and the actuating fluid common rail;

an actuating fluid check valve arranged in fluid communication between the actuating fluid port of the actuating fluid compressor cell and the actuating fluid storage chamber, said actuating fluid check valve operable to allow only one-way

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64 fluid flow from the actuating fluid compressor chamber to the actuating fluid storage
65 chamber;

66 a hydraulically-actuatable intake poppet valve associated with the air intake
67 port of the combustion cell and having an actuating fluid chamber and a piston
68 portion positioned in the actuating fluid chamber, said intake poppet valve
69 selectively operable to reciprocally move between i) a closed position at which the
70 intake poppet valve closes the air intake port and thereby closes fluid
71 communication between the air storage chamber and the combustion chamber via
72 the air intake port and ii) an opened position at which the intake poppet valve opens
73 the air intake port and thereby opens fluid communication between the air storage
74 chamber and the combustion chamber via the air intake port;

0" 75 an electronically-controllable magnetically-latchable three-way first control
76 valve arranged in fluid communication between the actuating fluid common rail and
77 the actuating fluid chamber of the intake valve, said first control valve including a
78 magnetically-latchable spool having one end portion and an opposite end portion and
79 movable between a closed position and an opened position, a closing-direction
80 electrical coil located proximate the one end portion of the spool, and an opening-
81 direction electrical coil located proximate the opposite end portion of the spool, said
82 closing-direction electrical coil selectively operable to electromagnetically pull the
83 spool towards its closed position at which the spool of the first control valve closes
84 fluid communication between the actuating fluid common rail and the actuating fluid
85 chamber of the intake poppet valve and opens fluid communication between the
86 actuating fluid drain passage and the actuating fluid chamber of the intake poppet
87 valve thereby allowing the intake poppet valve to be moved towards its closed
88 position, said opening-direction electrical coil selectively operable to
89 electromagnetically pull the spool towards its opened position at which the spool of
90 the first control valve opens fluid communication between the actuating fluid
91 common rail and the actuating fluid chamber of the intake poppet valve and closes
92 fluid communication between the actuating fluid drain passage and the actuating
93 fluid chamber of the intake poppet valve thereby allowing the intake poppet valve to
94 be hydraulically moved towards its opened position;

95 a hydraulically-actuatable exhaust poppet valve associated with the exhaust
96 port of the combustion cell and having an actuating fluid chamber and a piston
97 portion positioned in the actuating fluid chamber, said exhaust poppet valve
98 selectively operable to reciprocally move between i) a closed position at which the
99 exhaust poppet valve closes the exhaust port and thereby closes fluid communication
100 between the combustion chamber and the exhaust port and ii) an opened position at
101 which the exhaust poppet valve opens the exhaust port and thereby opens fluid
102 communication between the combustion chamber and the exhaust port;

103 an electronically-controllable magnetically-latchable three-way second
104 control valve arranged in fluid communication between the actuating fluid common
105 rail and the actuating fluid chamber of the exhaust poppet valve, said second control
106 valve including a magnetically-latchable spool having one end portion and an
107 opposite end portion and movable between a closed position and an opened position,
108 a closing-direction electrical coil located proximate the one end portion of the spool,
109 and an opening-direction electrical coil located proximate the opposite end portion
110 of the spool, said closing-direction electrical coil selectively operable to
111 electromagnetically pull the spool towards its closed position at which the spool of
112 the second control valve closes fluid communication between the actuating fluid
113 common rail and the actuating fluid chamber of the exhaust poppet valve and opens
114 fluid communication between the actuating fluid drain passage and the actuating
115 fluid chamber of the exhaust poppet valve thereby allowing the exhaust poppet valve
116 to be moved towards its closed position, said opening-direction electrical coil
117 selectively operable to electromagnetically pull the spool towards its opened position
118 at which the spool of the second control valve opens fluid communication between
119 the actuating fluid common rail and the actuating fluid chamber of the exhaust
120 poppet valve and closes fluid communication between the actuating fluid drain
121 passage and the actuating fluid chamber of the exhaust poppet valve thereby
122 allowing the exhaust poppet valve to be hydraulically moved towards its opened
123 position; and

124 a power piston positioned in the combustion chamber and operable to
125 reciprocally move therein between i) an expansion position at which the combustion

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126 chamber reaches its maximum volume and ii) a contraction position at which the
127 combustion chamber reaches its minimum volume.

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1 32. An internal combustion engine, comprising:

2 a plurality of power modules connected to generate work together wherein
3 each power module separately includes an air compressor cell defining a variable-
4 volume air compressor chamber, an air supply port, and an air exit port, said air
5 supply port and air exit port each arranged in fluid communication with the air
6 compressor chamber, said air supply port adapted to communicate with a source of
7 supply air; an electronically-controllable magnetically-latchable air supply valve
8 associated with the air supply port and selectively operable to move between i) a
9 closed position at which the air supply valve closes the air supply port and thereby
10 closes fluid communication between the source of supply air and the air compressor
11 chamber via the air supply port and ii) an opened position at which the air supply
12 valve opens the air supply port and thereby opens fluid communication between the
13 source of supply air and the air compressor chamber via the air supply port; an air
14 pump piston positioned in the air compressor chamber and operable to move
15 between i) an expansion position at which the air compressor chamber reaches its
16 maximum volume and ii) a contraction position at which the air compressor chamber
17 reaches its minimum volume; a combustion cell defining a variable-volume
18 combustion chamber separate from the air compressor chamber, an air intake port,
19 an exhaust port, and an actuating fluid common rail adapted to be arranged in fluid
20 communication with a source of pressurized actuating fluid, said air intake port and
21 exhaust port each arranged in fluid communication with the combustion chamber; an
22 actuating fluid drain passage; an air storage chamber arranged in fluid
23 communication between the air exit port of the air compressor cell and the air intake
24 port of the combustion cell; a hydraulically-actuatable intake valve associated with
25 the air intake port of the combustion cell and having an actuating fluid chamber and
26 a piston portion positioned in the acting fluid chamber, said intake valve selectively
27 operable to move between i) a closed position at which the intake valve closes the air
28 intake port and thereby closes fluid communication between the air storage chamber
29 and the combustion chamber via the air intake port and ii) an opened position at

30 which the intake valve opens the air intake port and thereby opens fluid
31 communication between the air storage chamber and the combustion chamber via
32 the air intake port; an electronically-controllable magnetically-latchable first control
33 valve arranged in fluid communication between the actuating fluid common rail and
34 the actuating fluid chamber of the intake valve, said first control valve selectively
35 operable to move between i) a closed position at which the first control valve closes
36 fluid communication between the actuating fluid common rail and the actuating fluid
37 chamber of the intake valve and opens fluid communication between the actuating
38 fluid drain passage and the actuating fluid chamber of the intake valve thereby
39 allowing the intake valve to be moved towards its closed position and ii) an opened
40 position at which the first control valve opens fluid communication between the
41 actuating fluid common rail and the actuating fluid chamber of the intake valve and
42 closes fluid communication between the actuating fluid drain passage and the
43 actuating fluid chamber of the intake valve thereby allowing the intake valve to be
44 hydraulically moved towards its opened position; a hydraulically-actuatable exhaust
45 valve associated with the exhaust port of the combustion cell and having an
46 actuating fluid chamber and a piston portion positioned in the actuating fluid
47 chamber, said exhaust valve selectively operable to move between i) a closed
48 position at which the exhaust valve closes the exhaust port and thereby closes fluid
49 communication between the combustion chamber and the exhaust port and ii) an
50 opened position at which the exhaust valve opens the exhaust port and thereby opens
51 fluid communication between the combustion chamber and the exhaust port; an
52 electronically-controllable magnetically-latchable second control valve arranged in
53 fluid communication between the actuating fluid common rail and the actuating fluid
54 chamber of the exhaust valve, said second control valve selectively operable to move
55 between i) a closed position at which the second control valve closes fluid
56 communication between the actuating fluid common rail and the actuating fluid
57 chamber of the exhaust valve and opens fluid communication between the actuating
58 fluid drain passage and the actuating fluid chamber of the exhaust valve thereby
59 allowing the exhaust valve to be moved towards its closed position and ii) an opened
60 position at which the second control valve opens fluid communication between the
61 actuating fluid common rail and the actuating fluid chamber of the exhaust valve and

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62 closes fluid communication between the actuating fluid drain passage and the
63 actuating fluid chamber of the exhaust valve thereby allowing the exhaust valve to
64 be hydraulically moved towards its opened position; and a power piston positioned
65 in the respective combustion chamber and operable to move therein between i) an
66 expansion position at which the respective combustion chamber reaches its
67 maximum volume and ii) a contraction position at which the respective combustion
68 chamber reaches its minimum volume; wherein said air compressor chamber and air
69 storage chamber of each power module are isolated from fluid communication and
70 independently operable with respect to the air compressor chamber and air storage
71 chamber of any other said power module of the internal combustion engine.

36
33.

An internal combustion engine, comprising:

2 a plurality of power modules connected to generate work together wherein
3 each power module separately includes an air compressor cell defining a variable-
4 volume air compressor chamber, an air supply port, and an air exit port, said air
5 supply port and air exit port each arranged in fluid communication with the air
6 compressor chamber, said air supply port adapted to communicate with a source of
7 supply air; an air supply valve associated with the air supply port and selectively
8 operable to move between i) a closed position at which the air supply valve closes
9 the air supply port and thereby closes fluid communication between the source of
10 supply air and the air compressor chamber via the air supply port and ii) an opened
11 position at which the air supply valve opens the air supply port and thereby opens
12 fluid communication between the source of supply air and the air compressor
13 chamber via the air supply port; an air pump piston positioned in the air compressor
14 chamber and operable to move between i) an expansion position at which the air
15 compressor chamber reaches its maximum volume and ii) a contraction position at
16 which the air compressor chamber reaches its minimum volume; a combustion cell
17 defining a variable-volume combustion chamber separate from the air compressor
18 chamber, an air intake port, and an exhaust port, said air intake port and exhaust port
19 each arranged in fluid communication with the combustion chamber; an air storage
20 chamber arranged in fluid communication between the air exit port of the air
21 compressor cell and the air intake port of the combustion cell; an intake valve

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associated with the air intake port of the combustion cell and selectively operable to move between i) a closed position at which the intake valve closes the air intake port and thereby closes fluid communication between the air storage chamber and the combustion chamber via the air intake port and ii) an opened position at which the intake valve opens the air intake port and thereby opens fluid communication between the air storage chamber and the combustion chamber via the air intake port; an exhaust valve associated with the exhaust port of the combustion cell and selectively operable to move between i) a closed position at which the exhaust valve closes the exhaust port and thereby closes fluid communication between the combustion chamber and the exhaust port and ii) an opened position at which the exhaust valve opens the exhaust port and thereby opens fluid communication between the combustion chamber and the exhaust port; and a power piston positioned in the respective combustion chamber and operable to move therein between i) an expansion position at which the respective combustion chamber reaches its maximum volume and ii) a contraction position at which the respective combustion chamber reaches its minimum volume; wherein said air compressor chamber and air storage chamber of each power module are isolated from fluid communication and independently operable with respect to the air compressor chamber and air storage chamber of any other said power module of the internal combustion engine, further including a separate electronic control unit associated with each power module, each electronic control unit operable to selectively and independently control the operation of the respective air supply valve with digital pulses of electrical current.

³⁷
~~34~~ The internal combustion engine of claim ³⁶~~33~~, further including an air pressure sensor associated with each power module, said air pressure sensor operable to sense the pressure of air in the respective air storage chamber and provide the respective electronic control unit with a signal indicative of such pressure, said respective electronic control unit operable to move the respective air supply valve to its opened position in response to said pressure being below a threshold air pressure, said respective electronic control unit operable to move the respective air supply

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8 valve to its closed position in response to said pressure being at least the threshold
9 air pressure.
10

38
35. An internal combustion engine, comprising:

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1 a plurality of power modules connected to generate work together wherein
2 each power module separately includes an air compressor cell defining a variable-
3 volume air compressor chamber, an air supply port, and an air exit port, said air
4 supply port and air exit port each arranged in fluid communication with the air
5 compressor chamber, said air supply port adapted to communicate with a source of
6 supply air; an air supply valve associated with the air supply port and selectively
7 operable to move between i) a closed position at which the air supply valve closes
8 the air supply port and thereby closes fluid communication between the source of
9 supply air and the air compressor chamber via the air supply port and ii) an opened
10 position at which the air supply valve opens the air supply port and thereby opens
11 fluid communication between the source of supply air and the air compressor
12 chamber via the air supply port; an air pump piston positioned in the air compressor
13 chamber and operable to move between i) an expansion position at which the air
14 compressor chamber reaches its maximum volume and ii) a contraction position at
15 which the air compressor chamber reaches its minimum volume; a combustion cell
16 defining a variable-volume combustion chamber separate from the air compressor
17 chamber, an air intake port, and an exhaust port, said air intake port and exhaust port
18 each arranged in fluid communication with the combustion chamber; an air storage
19 chamber arranged in fluid communication between the air exit port of the air
20 compressor cell and the air intake port of the combustion cell; an intake valve
21 associated with the air intake port of the combustion cell and selectively operable to
22 move between i) a closed position at which the intake valve closes the air intake port
23 and thereby closes fluid communication between the air storage chamber and the
24 combustion chamber via the air intake port and ii) an opened position at which the
25 intake valve opens the air intake port and thereby opens fluid communication
26 between the air storage chamber and the combustion chamber via the air intake port;
27 an exhaust valve associated with the exhaust port of the combustion cell and
28 selectively operable to move between i) a closed position at which the exhaust valve
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30 closes the exhaust port and thereby closes fluid communication between the
31 combustion chamber and the exhaust port and ii) an opened position at which the
32 exhaust valve opens the exhaust port and thereby opens fluid communication
33 between the combustion chamber and the exhaust port; and a power piston
34 positioned in the respective combustion chamber and operable to move therein
35 between i) an expansion position at which the respective combustion chamber
36 reaches its maximum volume and ii) a contraction position at which the respective
37 combustion chamber reaches its minimum volume; wherein said air compressor
38 chamber and air storage chamber of each power module are isolated from fluid
39 communication and independently operable with respect to the air compressor
40 chamber and air storage chamber of any other said power module of the internal
41 combustion engine, wherein each control unit is operable to selectively and
42 independently control the operation of the respective air supply valve in response to
43 at least one sensed parameter selected from the group of air temperature, air
44 manifold pressure, actuating fluid temperature, actuating fluid pressure, barometric
45 pressure, throttle position, power piston position, engine brake signals, starter inputs,
46 and ignition switch position.

47

1 ³³
~~36.~~ The internal combustion engine of claim 32, wherein the air
2 compressor cell and combustion cell of each power module are located adjacent to
3 one another.

4
1 ³⁴
~~37.~~ The internal combustion engine of claim 32, wherein said power
2 modules are arranged substantially in-line relative to one another.

3
1 ³⁵
~~38.~~ The internal combustion engine of claim 32, wherein the air
2 compressor cells are arranged in an alternating and substantially in-line pattern with
3 respect to the combustion cells.

4

1 39. An internal combustion engine, comprising:
2 a plurality of power modules connected to generate work together wherein each
3 power module separately includes an actuating fluid compressor cell defining a

4 variable-volume actuating fluid compressor chamber and an actuating fluid port
5 arranged in fluid communication with the actuating fluid compressor chamber, said
6 actuating fluid port adapted to communicate with a source of actuating fluid; an
7 actuating fluid drain passage; an actuating fluid supply valve arranged in fluid
8 communication between the source of actuating fluid and the actuating fluid port and
9 selectively operable to move between i) a closed position at which the supply valve
10 closes fluid communication between the source of actuating fluid and the actuating
11 fluid compressor chamber via the actuating fluid port and ii) an opened position at
12 which the supply valve opens fluid communication between the source of actuating
13 fluid and the actuating fluid compressor chamber via the actuating fluid port; an
14 actuating fluid pump piston positioned in the actuating fluid compressor chamber
15 and operable to move therein between i) an expansion position at which the
16 actuating fluid compressor chamber reaches its maximum volume and ii) a
17 contraction position at which the actuating fluid compressor chamber reaches its
18 minimum volume; a combustion cell defining a variable-volume combustion
19 chamber, separate from the actuating fluid compressor chamber, an air intake port,
20 an exhaust port, and an actuating fluid common rail, said air intake port and exhaust
21 port each arranged in fluid communication with the combustion chamber; an
22 actuating fluid storage chamber arranged in fluid communication between the
23 actuating fluid port of the actuating fluid compressor cell and the actuating fluid
24 common rail; a hydraulically-actuatable intake valve associated with the air intake
25 port of the combustion cell and having an actuating fluid chamber and a piston
26 portion positioned in the actuating fluid chamber, said intake valve selectively
27 operable to move between i) a closed position at which the intake valve closes the air
28 intake port and thereby closes fluid communication between the air storage chamber
29 and the combustion chamber via the air intake port and ii) an opened position at
30 which the intake valve opens the air intake port and thereby opens fluid
31 communication between the air storage chamber and the combustion chamber via
32 the air intake port; an electronically-controllable magnetically-latchable first control
33 valve arranged in fluid communication between the actuating fluid common rail and
34 the actuating fluid chamber of the intake valve, said first control valve selectively
35 operable to move between i) a closed position at which the first control valve closes

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36 fluid communication between the actuating fluid common rail and the actuating fluid
37 chamber of the intake valve and opens fluid communication between the actuating
38 fluid drain passage and the actuating fluid chamber of the intake valve thereby
39 allowing the intake valve to be moved towards its closed position and ii) an opened
40 position at which the first control valve opens fluid communication between the
41 actuating fluid common rail and the actuating fluid chamber of the intake valve and
42 closes fluid communication between the actuating fluid drain passage and the
43 actuating fluid chamber of the intake valve thereby allowing the intake valve to be
44 hydraulically moved towards its opened position; a hydraulically-actuatable exhaust
45 valve associated with the exhaust port of the combustion cell and having an
46 actuating fluid chamber and a piston portion positioned in the actuating fluid
47 chamber, said exhaust valve selectively operable to move between i) a closed
48 position at which the exhaust valve closes the exhaust port and thereby closes fluid
49 communication between the combustion chamber and the exhaust port and ii) an
50 opened position at which the exhaust valve opens the exhaust port and thereby opens
51 fluid communication between the combustion chamber and the exhaust port; an
52 electronically-controllable magnetically-latchable second control valve arranged in
53 fluid communication between the actuating fluid common rail and the actuating fluid
54 chamber of the exhaust valve, said second control valve selectively operable to move
55 between i) a closed position at which the second control valve closes fluid
56 communication between the actuating fluid common rail and the actuating fluid
57 chamber of the exhaust valve and opens fluid communication between the actuating
58 fluid drain passage and the actuating fluid chamber of the exhaust valve thereby
59 allowing the exhaust valve to be moved towards its closed position and ii) an opened
60 position at which the second control valve opens fluid communication between the
61 actuating fluid common rail and the actuating fluid chamber of the exhaust valve and
62 closes fluid communication between the actuating fluid drain passage and the
63 actuating fluid chamber of the exhaust valve thereby allowing the exhaust valve to
64 be hydraulically moved towards its opened position; and a power piston positioned
65 in the combustion chamber and operable to move therein between i) an expansion
66 position at which the combustion chamber reaches its maximum volume and ii) a
67 contraction position at which the combustion chamber reaches its minimum volume;

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B'5
68 wherein said actuating fluid compressor chamber and actuating fluid storage
69 chamber of each power module are isolated from fluid communication and
70 independently operable with respect to the actuating fluid compressor chamber and
71 actuating fluid storage chamber of any other said power module of the internal
72 combustion engine.
73

1 40. The internal combustion engine of claim 39, wherein said
2 actuating fluid compressor cell and combustion cell of each power module are
3 located adjacent to one another.
4

B'6
1 41. The internal combustion engine of claim 39, wherein said power
2 modules are arranged substantially in-line relative to one another.
3

1 42. The internal combustion engine of claim 39, wherein the actuating
2 fluid compressor cells are arranged in an alternating and substantially in-line pattern
3 with respect to the combustion cells.
4

B'7
1 43. A two-stroke cycle power module, comprising:
2 a rotatable crankshaft;
3 a combustion chamber;
4 an actuating fluid drain passage;
5 an actuating fluid common rail adapted to be arranged in fluid
6 communication with a source of pressurized actuating fluid;
7 a movable power piston positioned in the combustion chamber and
8 coupled to the crankshaft for movement therewith;
9 an electronically-controllable hydraulically-actuatable intake valve having an
10 actuating fluid chamber and a piston portion positioned in the actuating fluid
11 chamber, said intake valve selectively operable to admit air into the combustion
12 chamber;
13 an electronically-controllable magnetically-latchable first control valve
14 arranged in fluid communication between the actuating fluid common rail and the
15 actuating fluid chamber of the intake valve, said first control valve selectively

operable to move between i) a closed position at which the first control valve closes fluid communication between the actuating fluid common rail and the actuating fluid chamber of the intake valve and opens fluid communication between the actuating fluid drain passage and the actuating fluid chamber of the intake valve thereby allowing the intake valve to be moved towards its closed position and ii) an opened position at which the first control valve opens fluid communication between the actuating fluid common rail and the actuating fluid chamber of the intake valve and closes fluid communication between the actuating fluid drain passage and the actuating fluid chamber of the intake valve thereby allowing the intake valve to be hydraulically moved towards its opened position;

an electronically-controllable hydraulically-actuatable exhaust valve having an actuating fluid chamber and a piston portion positioned in the actuating fluid chamber, said exhaust valve selectively operable to vent exhaust gas from the combustion chamber;

517 an electronically-controllable magnetically-latchable second control valve arranged in fluid communication between the actuating fluid common rail and the actuating fluid chamber of the exhaust valve, said second control valve selectively operable to move between i) a closed position at which the second control valve closes fluid communication between the actuating fluid common rail and the actuating fluid chamber of the exhaust valve and opens fluid communication between the actuating fluid drain passage and the actuating fluid chamber of the exhaust valve thereby allowing the exhaust valve to be moved towards its closed position and ii) an opened position at which the second control valve opens fluid communication between the actuating fluid common rail and the actuating fluid chamber of the exhaust valve and closes fluid communication between the actuating fluid drain passage and the actuating fluid chamber of the exhaust valve thereby allowing the exhaust valve to be hydraulically moved towards its opened position

an electronically-controllable hydraulically-actuatable fuel injector extending into the combustion chamber and selectively operable to inject fuel therein, wherein said injector includes an actuating fluid chamber, a piston portion positioned in the actuating fluid chamber, a check valve movable between a closed position at which the check valve blocks injection of fuel and an opened position at

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48 which the check valve opens injection of fuel, and an electronically-controllable
49 magnetically-latchable third control valve arranged in fluid communication between
50 the actuating fluid common rail and the actuating fluid chamber of the injector, said
51 third control valve selectively operable to move between i) a closed position at
52 which the third control valve closes fluid communication between the actuating fluid
53 common rail and the actuating fluid chamber of the injector and opens fluid
54 communication between the actuating fluid drain passage and the actuating fluid
55 chamber of the injector thereby allowing the check valve of the injector to be moved
56 towards its closed position and ii) an opened position at which the third control
57 valve opens fluid communication between the actuating fluid common rail and the
58 actuating fluid chamber of the injector and closes fluid communication between the
59 actuating fluid drain passage and the actuating fluid chamber of the injector thereby
60 allowing the check valve to be hydraulically moved towards its opened position,
61 wherein said crankshaft is selectively rotatable in one angular direction and a reverse
62 angular direction in response to selectable timing and sequence of operation of the
63 intake and exhaust valves and the fuel injector relative to the position of the power
64 piston.

44. A method of operating a two-stroke cycle power module having a
rotatable crankshaft; an air compressor cell defining a variable-volume air
compressor chamber, an air supply port, and an air exit port, said air supply port and
air exit port each arranged in fluid communication with the air compressor chamber,
said air supply port adapted to communicate with a source of supply air; an air
supply valve associated with the air supply port and selectively operable to move
between i) a closed position at which the air supply valve closes the air supply port
and thereby closes fluid communication between the source of supply air and the air
compressor chamber via the air supply port and ii) an opened position at which the
air supply valve opens the air supply port and thereby opens fluid communication
between the source of supply air and the air compressor chamber via the air supply
port; an air pump piston positioned in the air compressor chamber and operable to
move between i) an expansion position at which the air compressor chamber reaches
its maximum volume and ii) a contraction position at which the air compressor

15 chamber reaches its minimum volume; a combustion cell defining a variable-volume
16 combustion chamber separate from the air compressor chamber, an air intake port,
17 and an exhaust port, said air intake port and exhaust port each arranged in fluid
18 communication with the combustion chamber; an air storage chamber arranged in
19 fluid communication between the air exit port of the air compressor cell and the air
20 intake port of the combustion cell; an intake valve associated with the air intake port
21 of the combustion cell and selectively operable to move between i) a closed position
22 at which the intake valve closes the air intake port and thereby closes fluid
23 communication between the air storage chamber and the combustion chamber via
24 the air intake port and ii) an opened position at which the intake valve opens the air
25 intake port and thereby opens fluid communication between the air storage chamber
26 and the combustion chamber via the air intake port; an exhaust valve associated with
27 the exhaust port of the combustion cell and selectively operable to move between i)
28 a closed position at which the exhaust valve closes the exhaust port and thereby
29 closes fluid communication between the combustion chamber and the exhaust port
30 and ii) an opened position at which the exhaust valve opens the exhaust port and
31 thereby opens fluid communication between the combustion chamber and the
32 exhaust port; and a power piston positioned in the combustion chamber and coupled
33 to the crankshaft for movement therewith, said power piston operable to move in the
34 combustion chamber between i) an expansion position at which the combustion
35 chamber reaches its maximum volume corresponding to a 180° angular position of
36 the crankshaft and ii) a contraction position at which the combustion chamber
37 reaches its minimum volume corresponding to a 0° angular position of the
38 crankshaft, said method comprising the steps of:

39 moving the power piston from its contraction position and towards its
40 expansion position;

41 opening the exhaust valve when the power piston has been moved to a first
42 position corresponding to a first angular position of the crankshaft;

43 opening the intake valve when the power piston has been moved to a second
44 position corresponding to a second angular position of the crankshaft;

45 moving the power piston to its expansion position;

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46 moving the power piston from its expansion position and towards its
47 contraction position;
48 closing the exhaust valve when the power piston has been moved to a third
49 position corresponding to a third angular position of the crankshaft;
50 closing the intake valve when the power piston has been moved to a fourth
51 position corresponding to a fourth angular position of the crankshaft; and
52 moving the power piston to its contraction position.
53

1 45. The method of claim 44, wherein the angular distance between the
2 first and fourth angular positions is about 80°.
3

1 46. The method of claim 44, wherein the first angular position of the
2 crankshaft is about 140°, the second angular position of the crankshaft is about 160°,
3 the third angular position of the crankshaft is about 200°, and the fourth angular
4 position of the crankshaft is about 220°.
5

1 47. The method of claim 44, wherein during operation of the power
2 module the combustion chamber has a peak fluid pressure of about 13,790 kPa
3 (about 2000 psi) when the power piston is at its contraction position.
4

1 48. The method of claim 44, wherein during operation of the power
2 module the combustion chamber has a residual fluid pressure greater than
3 atmospheric pressure when the power piston is at its expansion position.
4

1 49. The method of claim 48, wherein the residual fluid pressure in the
2 combustion chamber is at least about 138 kPa (about 20 psi).
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1 50. The method of claim 48, wherein the residual fluid pressure in the
2 combustion chamber is in the range of about 138 to 207 kPa (about 20 to 30 psi).
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1 51. A power module, comprising:
2 an actuating fluid compressor cell defining a variable-volume actuating fluid
3 compressor chamber and an actuating fluid port arranged in fluid communication
4 with the actuating fluid compressor chamber, said actuating fluid port adapted to
5 communicate with a source of actuating fluid;
6 an actuating fluid drain passage;
7 an actuating fluid supply valve arranged in fluid communication between the
8 source of actuating fluid and the actuating fluid port and selectively operable to
9 move between i) a closed position at which the supply valve closes fluid
10 communication between the source of actuating fluid and the actuating fluid
11 compressor chamber via the actuating fluid port and ii) an opened position at which
12 the supply valve opens fluid communication between the source of actuating fluid
13 and the actuating fluid compressor chamber via the actuating fluid port;
14 an actuating fluid pump piston positioned in the actuating fluid compressor
15 chamber and operable to move therein between i) an expansion position at which
16 the actuating fluid compressor chamber reaches its maximum volume and ii) a
17 contraction position at which the actuating fluid compressor chamber reaches its
18 minimum volume;
19 a combustion cell defining a variable-volume combustion chamber, separate
20 from the actuating fluid compressor chamber, an air intake port, an exhaust port, and
21 an actuating fluid common rail, said air intake port and exhaust port each arranged in
22 fluid communication with the combustion chamber;
23 an actuating fluid storage chamber arranged in fluid communication between
24 the actuating fluid port of the actuating fluid compressor cell and the actuating fluid
25 common rail;
26 an intake valve associated with the air intake port of the combustion cell and
27 operable to move between i) a closed position at which the intake valve closes the air
28 intake port and thereby closes fluid communication to the combustion chamber via
29 the air intake port and ii) an opened position at which the intake valve opens the air
30 intake port and thereby opens fluid communication to the combustion chamber via
31 the air intake port;

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32 an exhaust valve associated with the exhaust port of the combustion cell and
33 selectively operable to move between i) a closed position at which the exhaust valve
34 closes the exhaust port and thereby closes fluid communication between the
35 combustion chamber and the exhaust port and ii) an opened position at which the
36 exhaust valve opens the exhaust port and thereby opens fluid communication
37 between the combustion chamber and the exhaust port; and

38 an electronically-controllable hydraulically-actuatable fuel injector extending
39 into the combustion chamber and selectively operable to inject fuel therein, said fuel
40 injector including an actuating fluid chamber, a piston portion positioned in the
41 actuating fluid chamber, a check valve movable between a closed position at which
42 the check valve blocks injection of fuel and an opened position at which the check
43 valve opens injection of fuel, and an electronically-controllable fluid control valve
44 arranged in fluid communication between the actuating fluid common rail and the
45 actuating fluid chamber of the injector, said control valve selectively operable to
46 move between i) a closed position at which the control valve closes fluid
47 communication between the actuating fluid common rail and the actuating fluid
48 chamber of the injector and opens fluid communication between the actuating fluid
49 drain passage and the actuating fluid chamber of the injector thereby allowing the
50 check valve of the injector to be moved towards its closed position and ii) an opened
51 position at which the control valve opens fluid communication between the actuating
52 fluid common rail and the actuating fluid chamber of the injector and closes fluid
53 communication between the actuating fluid drain passage and the actuating fluid
54 chamber of the injector thereby allowing the check valve to be hydraulically moved
55 towards its opened position; and

56 a power piston positioned in the combustion chamber and operable to move
57 therein between i) an expansion position at which the combustion chamber reaches
58 its maximum volume and ii) a contraction position at which the combustion chamber
59 reaches its minimum volume.

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1 52. The power module of claim 51, wherein said control valve is
2 magnetically latchable in at least one of its closed and opened positions.
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1 53. The power module of claim 51, further including a check
2 valve arranged in fluid communication between the actuating fluid port of the
3 actuating fluid compressor cell and the actuating fluid storage chamber, said check
4 valve operable to allow only one-way fluid flow from the actuating fluid compressor
5 chamber to the actuating fluid storage chamber.

1 54. The power module of claim 51, wherein said actuating fluid supply
2 valve includes a digitally-controlled two-way valve including a movable
3 magnetically-latchable spool having one end portion and an opposite end portion, a
4 closing-direction electrical coil located proximate the one end portion of the spool,
5 and an opening-direction electrical coil located proximate the opposite end portion
6 of the spool, said closing-direction electrical coil selectively operable to
7 electromagnetically pull the spool towards one state corresponding to the closed
8 position of the actuating fluid supply valve, said opening-direction electrical coil
9 selectively operable to electromagnetically pull the spool towards another state
10 corresponding to the opened position of the actuating fluid supply valve.

1 55. The power module of claim 51, further including an electronic control
2 unit operable to control the selectable operation of each said electronically-
3 controllable valves.

1 56. The power module of claim 55, further including an actuating fluid
2 pressure sensor operable to i) sense the pressure of actuating fluid in the actuating
3 fluid storage chamber and ii) provide the electronic control unit with an actuating
4 fluid pressure signal indicative of said pressure, said electronic control unit operable
5 to independently control the operation of the actuating fluid supply valve in response
6 to said actuating fluid pressure signal.

1 57. The power module of claim 51, wherein said injector is a multiple
2 stage injector.

1 58. The power module of claim 51, wherein said actuating fluid

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2 storage chamber is integrally formed with the actuating fluid compressor cell.

3

1 59. The power module of claim 51, wherein said actuating fluid storage
2 chamber is connected to the actuating fluid compressor cell.

3

1 60. The power module of claim 51, wherein said intake and exhaust
2 valves each further include a return spring operable to bias the respective valve
3 towards its closed position.

4

1 61. The power module of claim 51, wherein the actuating fluid
2 compressor cell and the combustion cell are integrally formed with one another by a
3 common housing.

4

1 62. The power module of claim 51, wherein the actuating fluid
2 compressor cell and the combustion cell are connected together as a compact unit.

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1 63. The power module of claim 51, wherein the actuating fluid pump
2 piston and the power piston are movable by a common drive device.

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